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(45) **Date of Patent:** Jun. 9, 2015

- (58) **Field of Classification Search**
USPC 438/513, 530
See application file for complete search history.

- (56)
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- Notification of the First Office Action issued by the State Intellectual Property Office of People's Republic of China on Jun. 27, 2014.

- Notification of the Second Office Action issued by the State Intellectual Property Office of People's Republic of China on Jan. 27, 2015.

- Primary Examiner* — Alexander Ghyka

- (74) *Attorney, Agent, or Firm* — IP & T Group LLP

- (57) **ABSTRACT**

- A doping method that forms a doped region at a desired location of a three-dimensional (3D) conductive structure, controls the doping depth and doping dose of the doped region relatively easily, has a shallow doping depth, and prevents a floating body effect. A semiconductor device is fabricated using the same doping method. The method includes, forming a conductive structure having a sidewall, exposing a portion of the sidewall of the conductive structure, and forming a doped region in the exposed portion of the sidewall by performing a plasma doping process.

- 14 Claims, 16 Drawing Sheets**

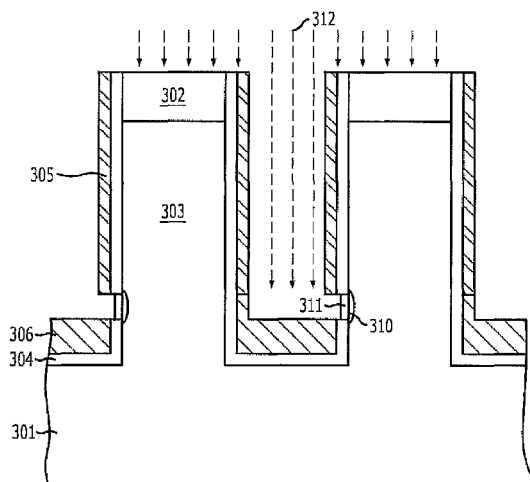


FIG. 1
(PRIOR ART)

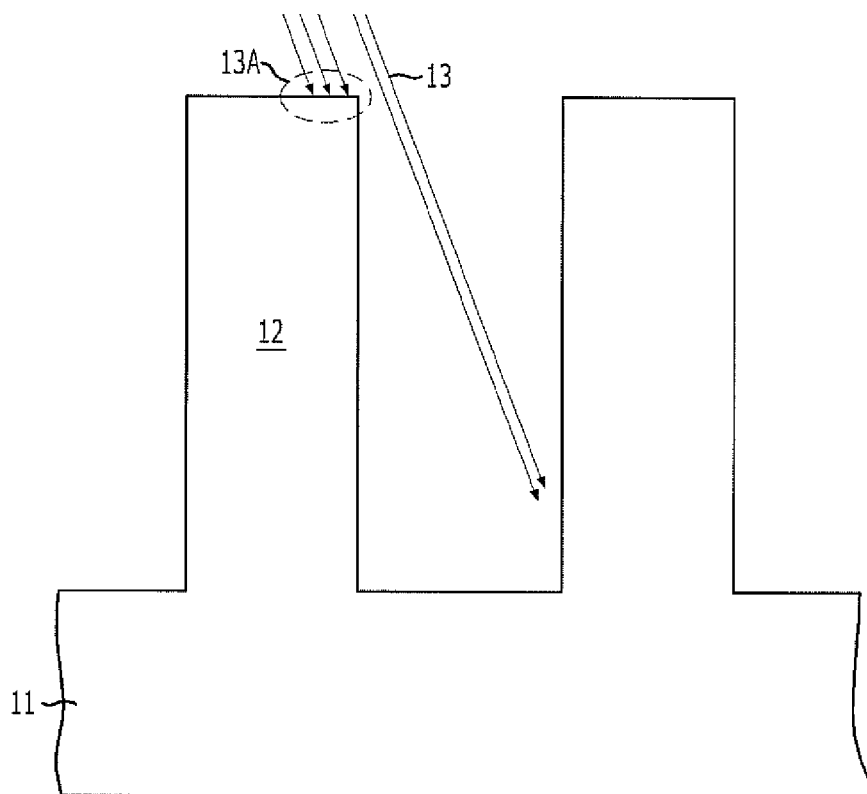


FIG. 2A

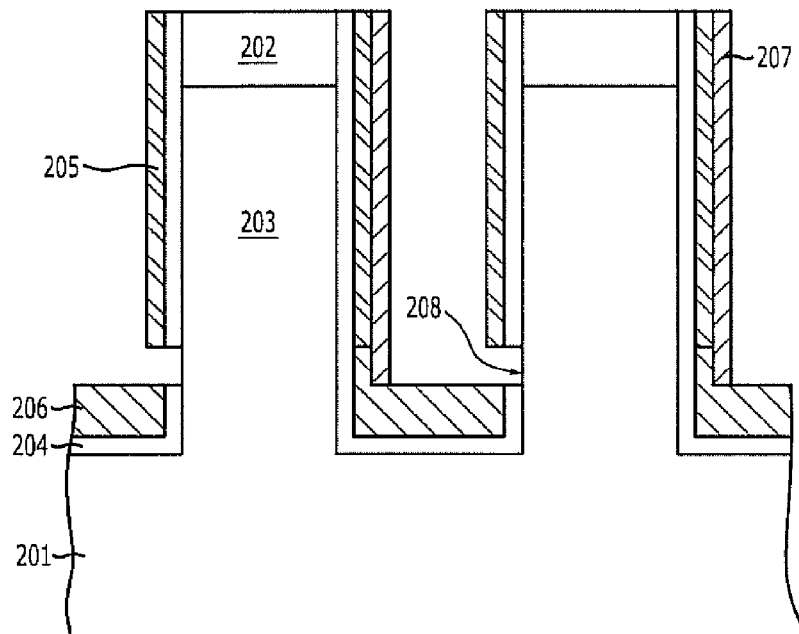


FIG. 2B

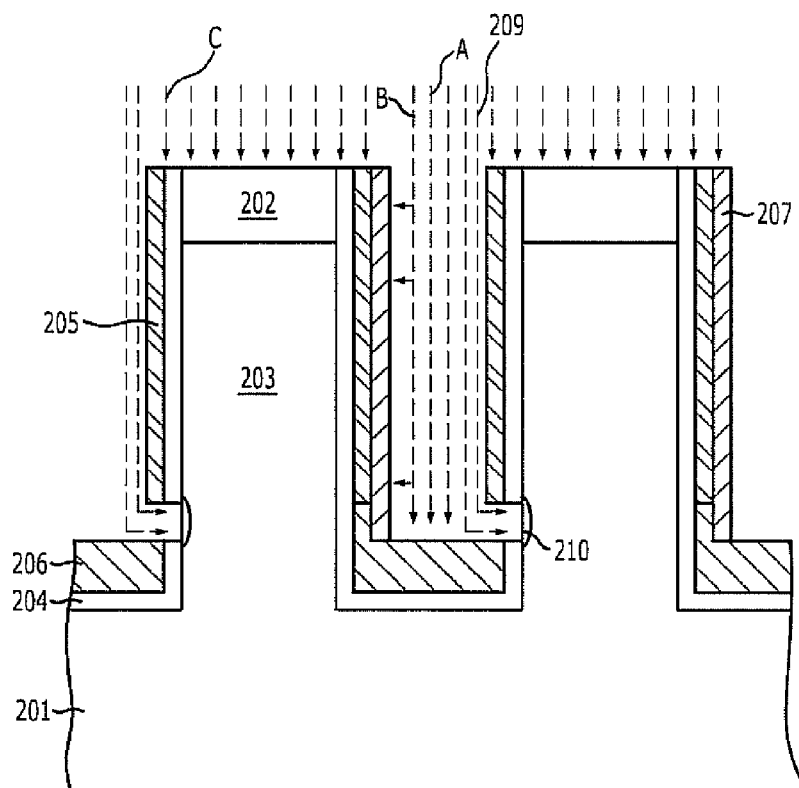


FIG. 3A

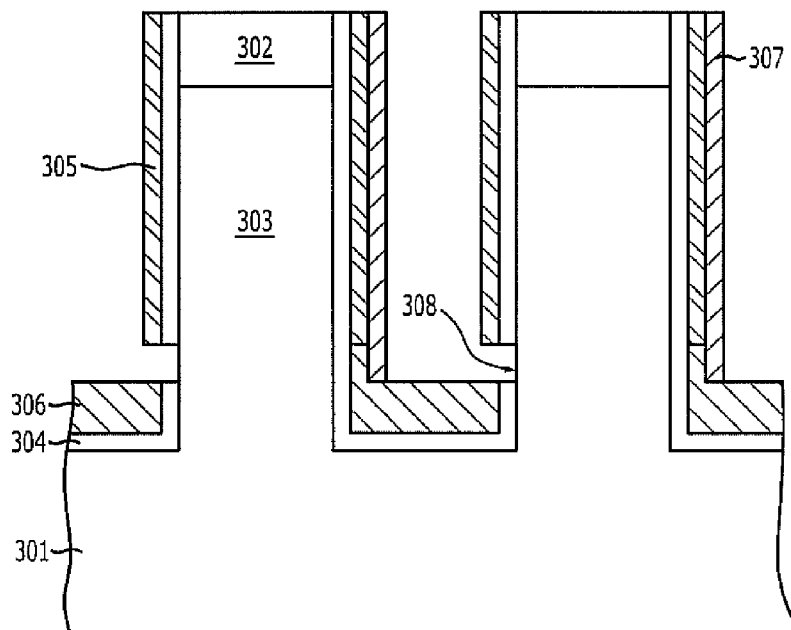


FIG. 3B

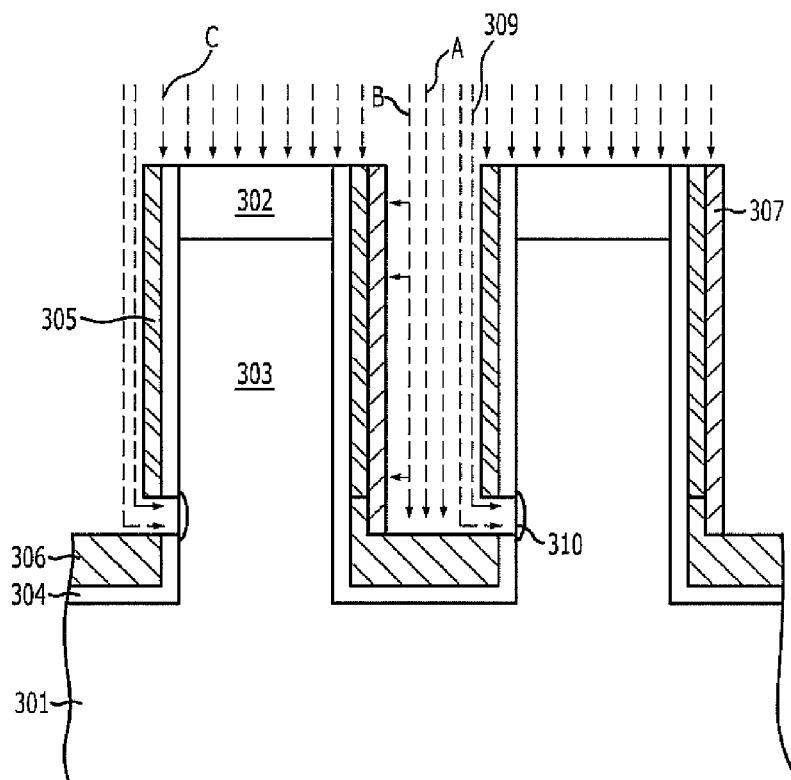


FIG. 3C

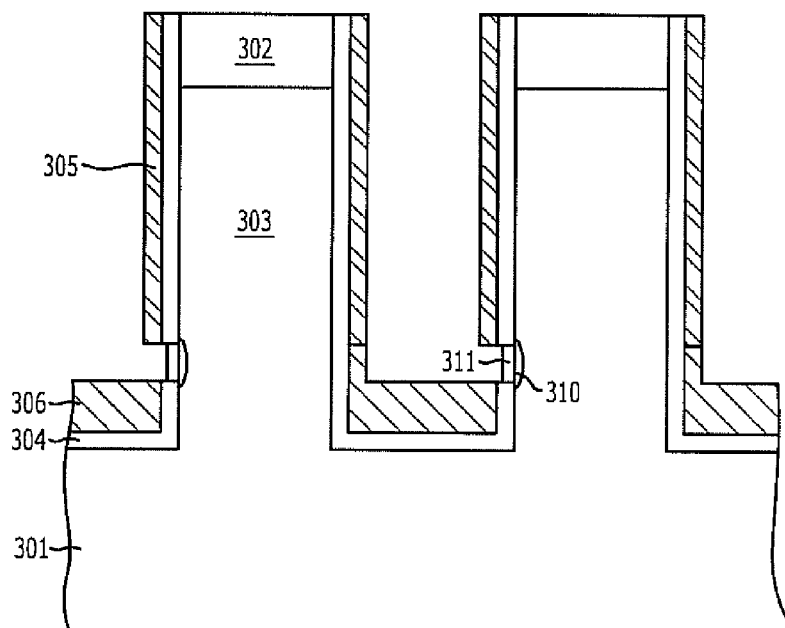


FIG. 3D

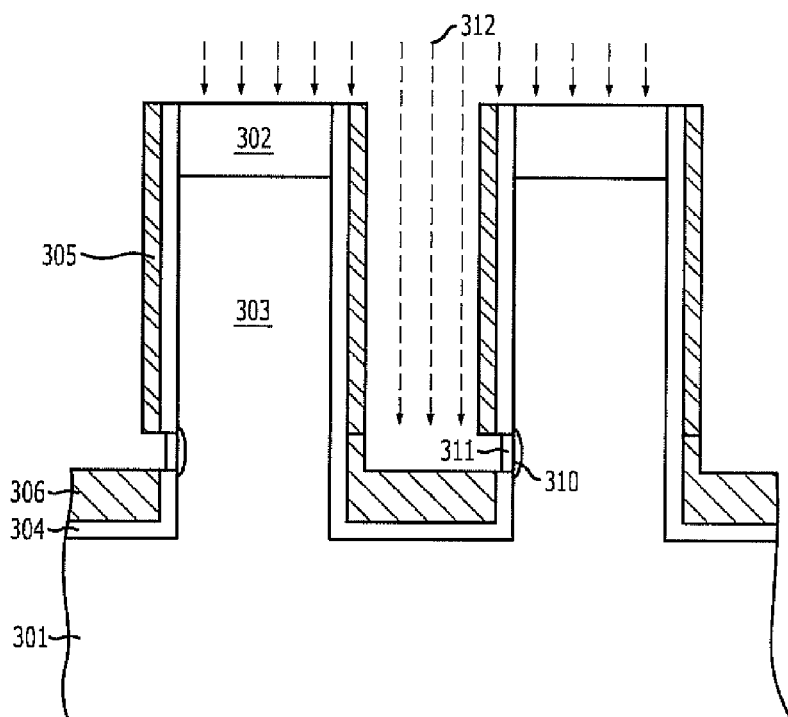


FIG. 3E

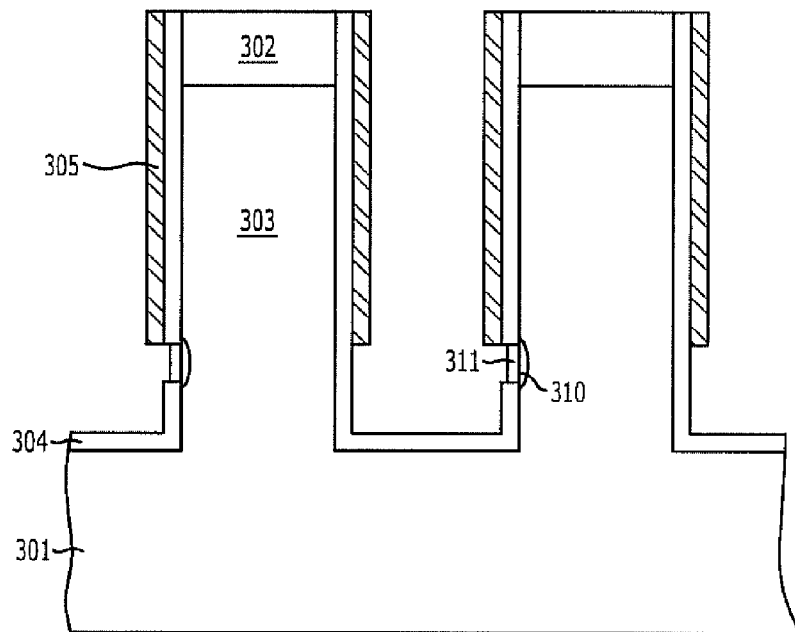


FIG. 4A

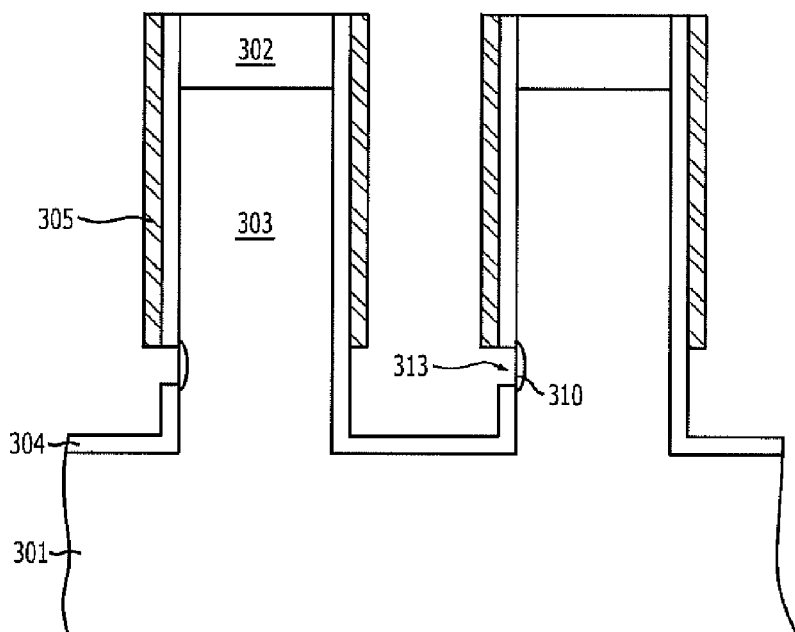


FIG. 4B

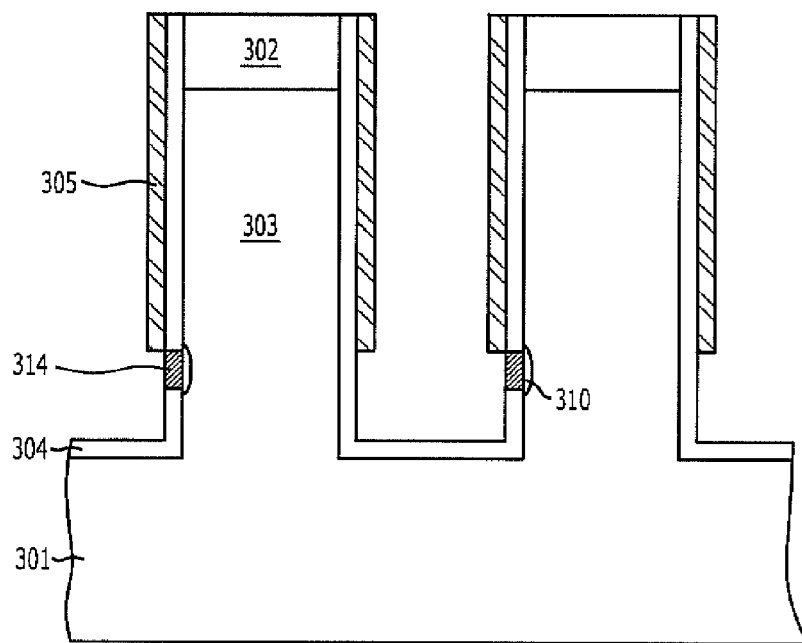


FIG. 4C

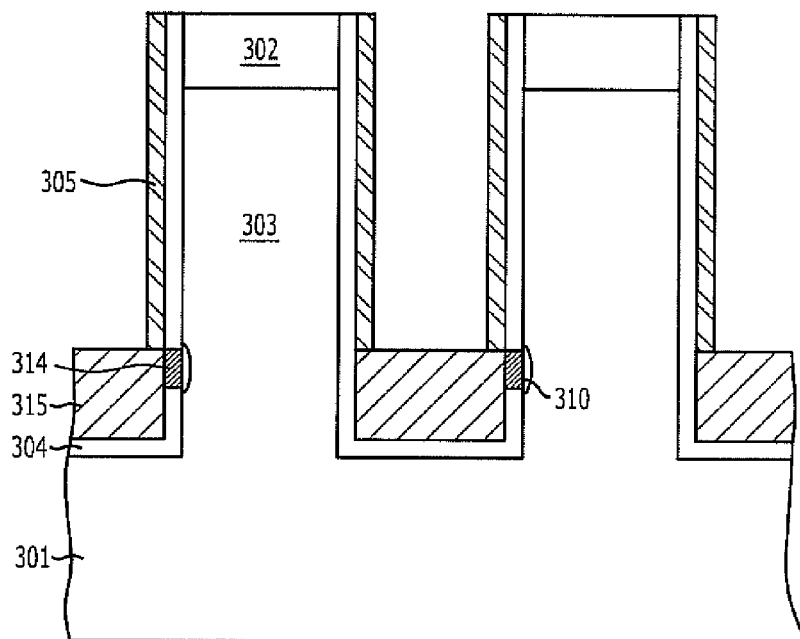


FIG. 5A

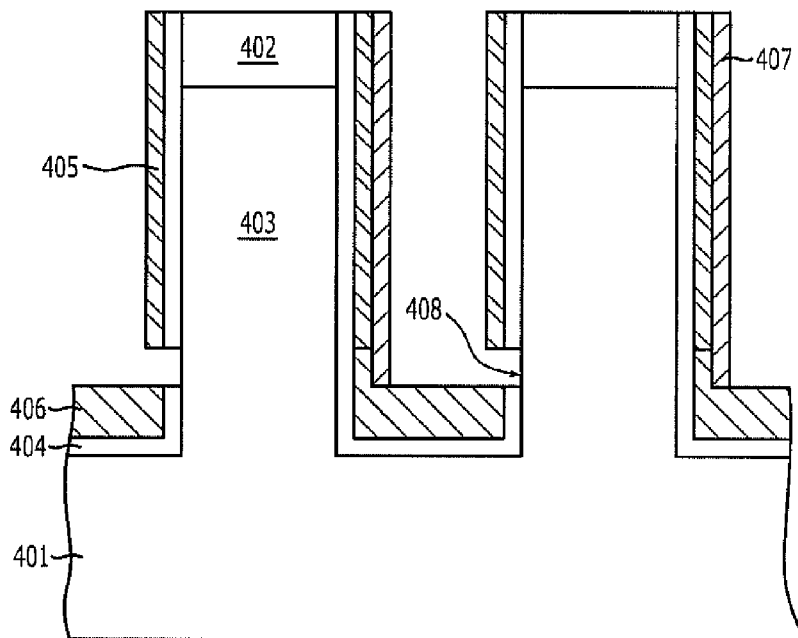


FIG. 5B

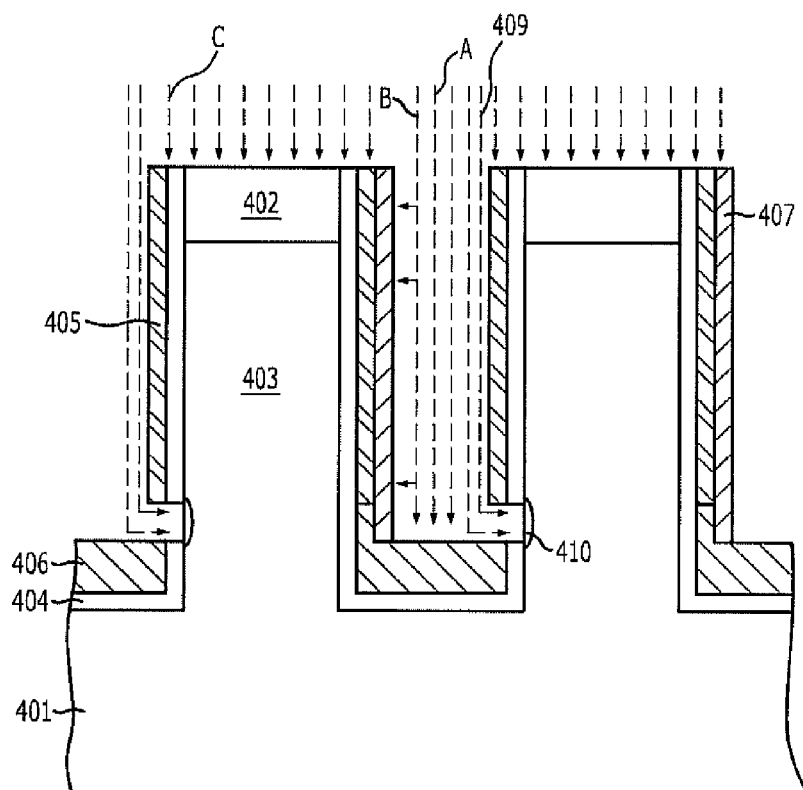


FIG. 5C

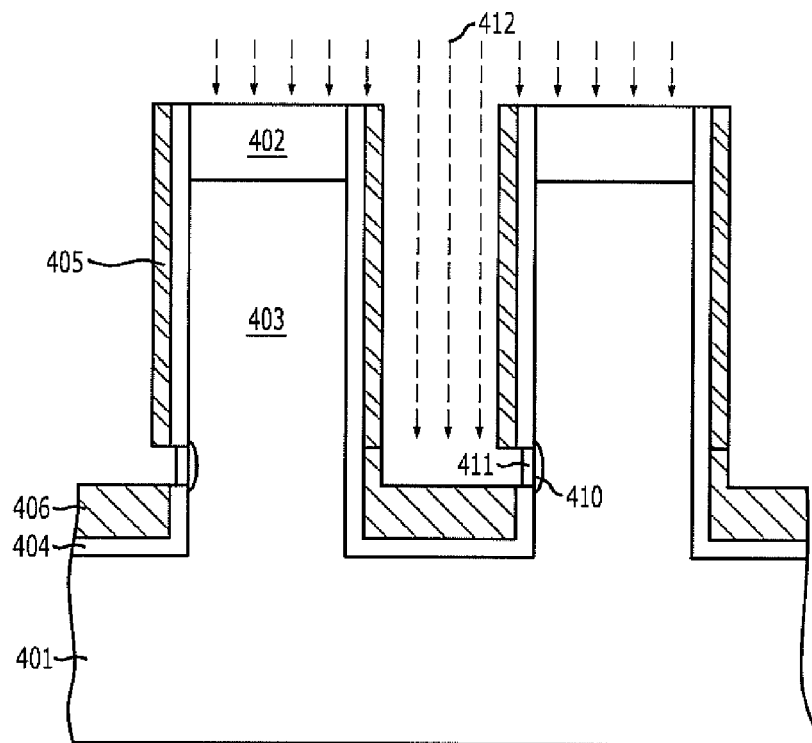


FIG. 5D

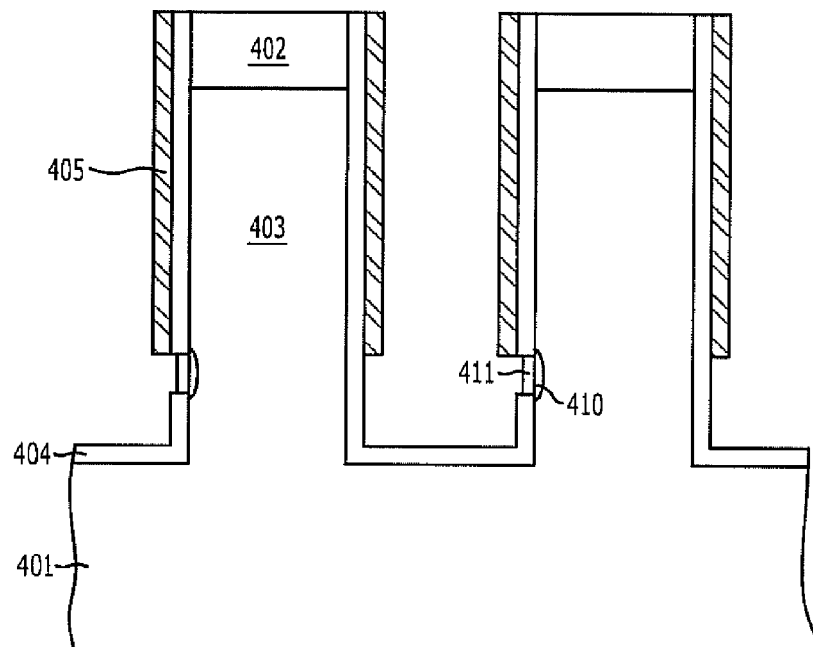


FIG. 6A

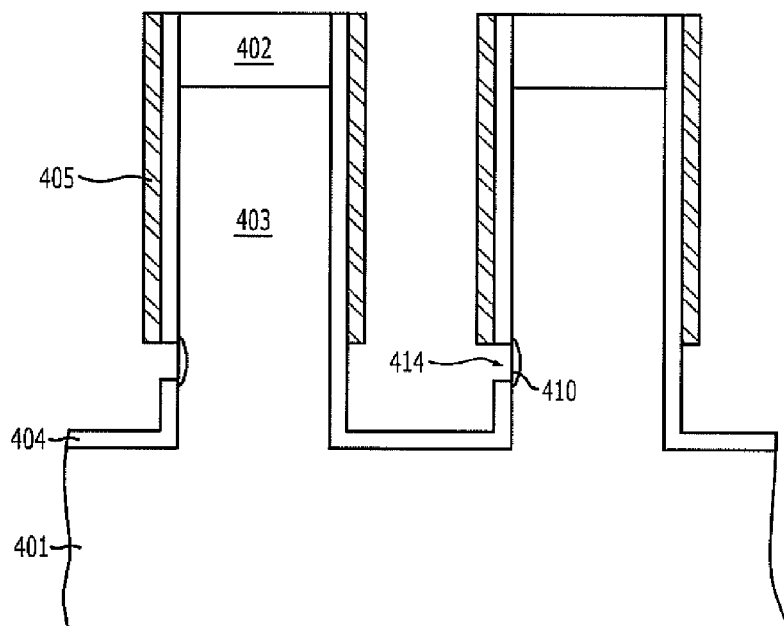


FIG. 6B

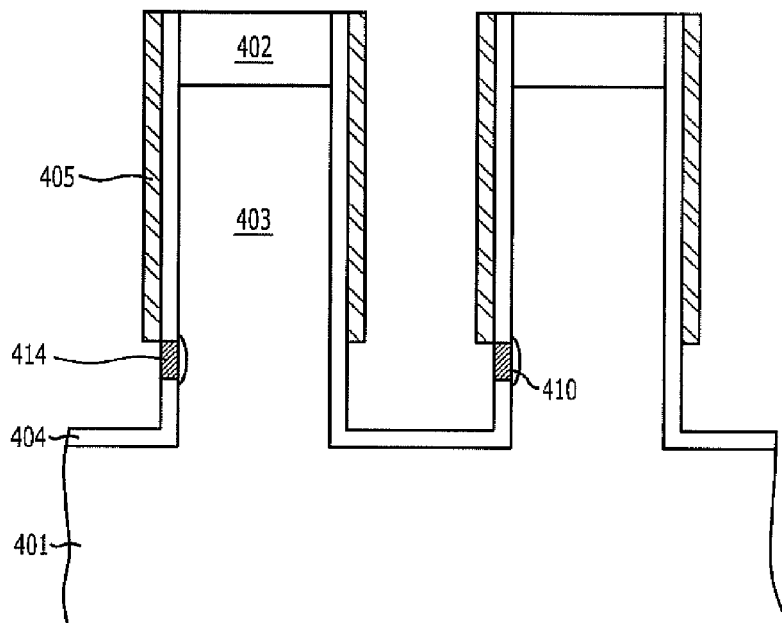


FIG. 6C

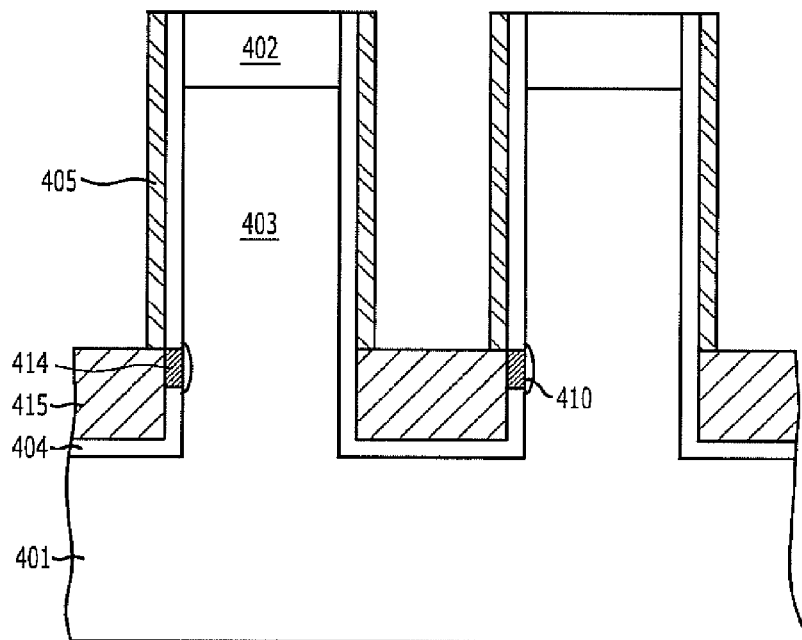


FIG. 7A

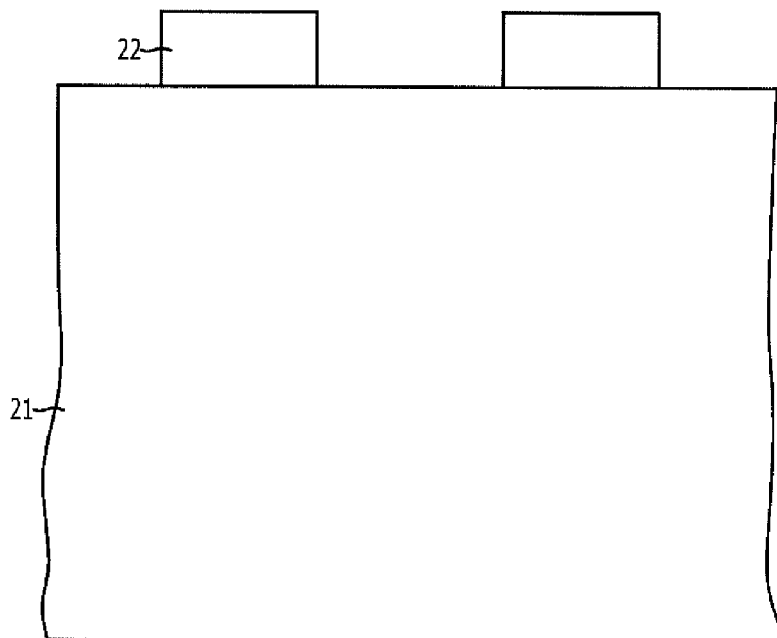


FIG. 7B

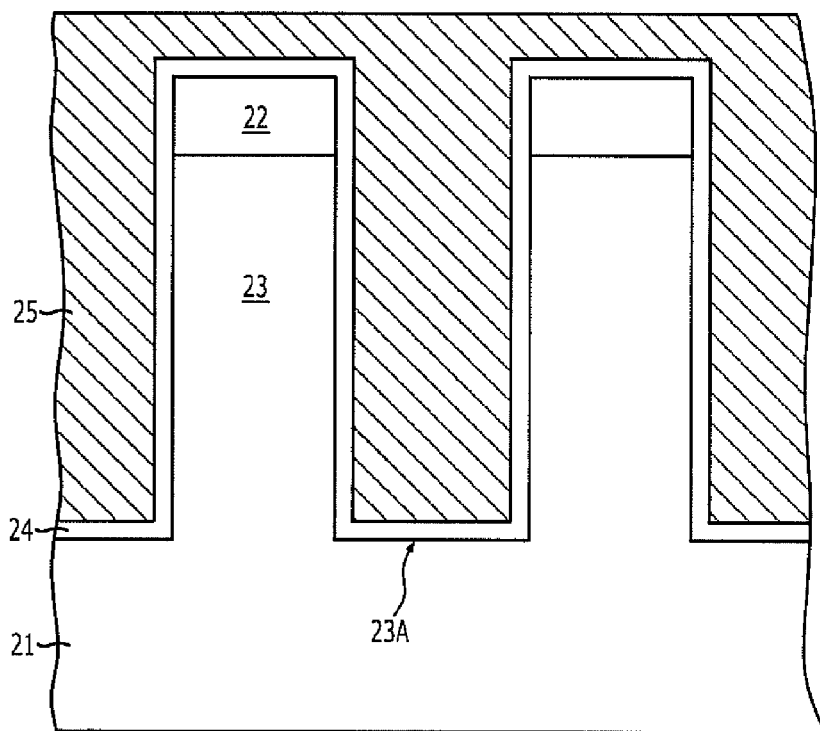


FIG. 7C

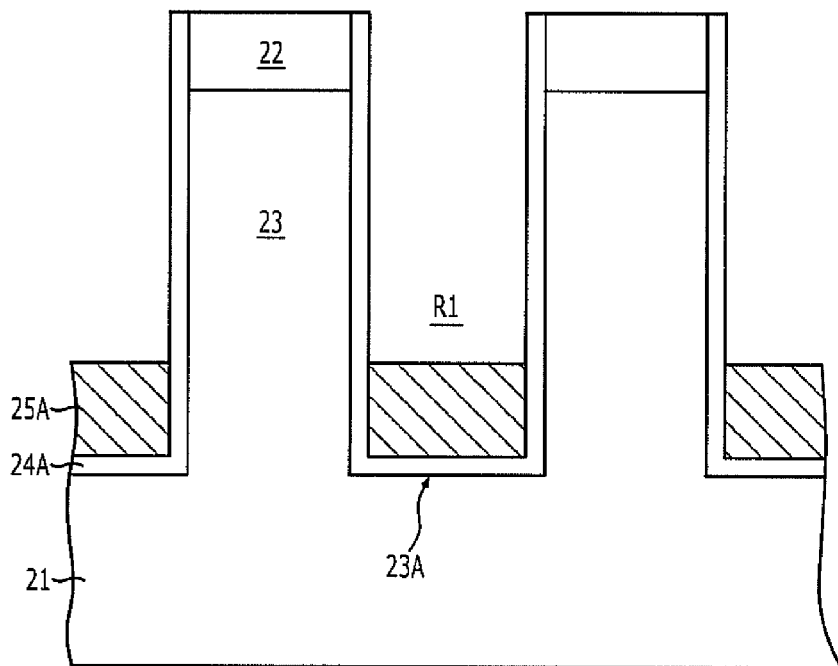


FIG. 7D

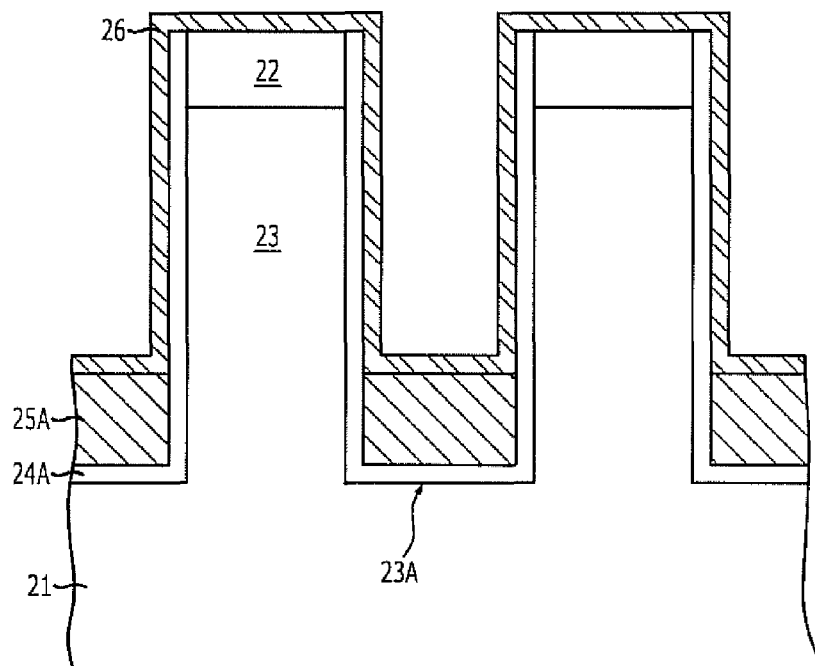


FIG. 7E

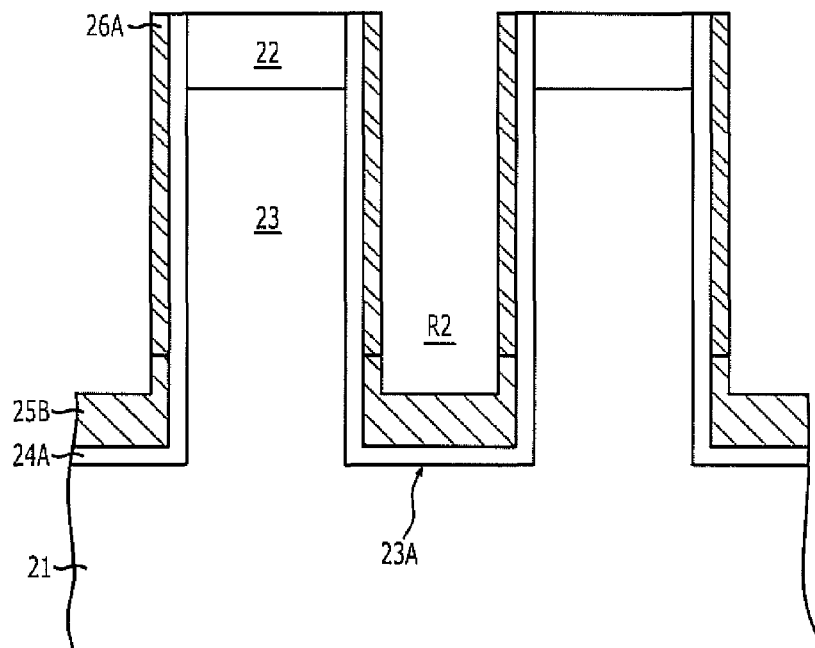


FIG. 7F

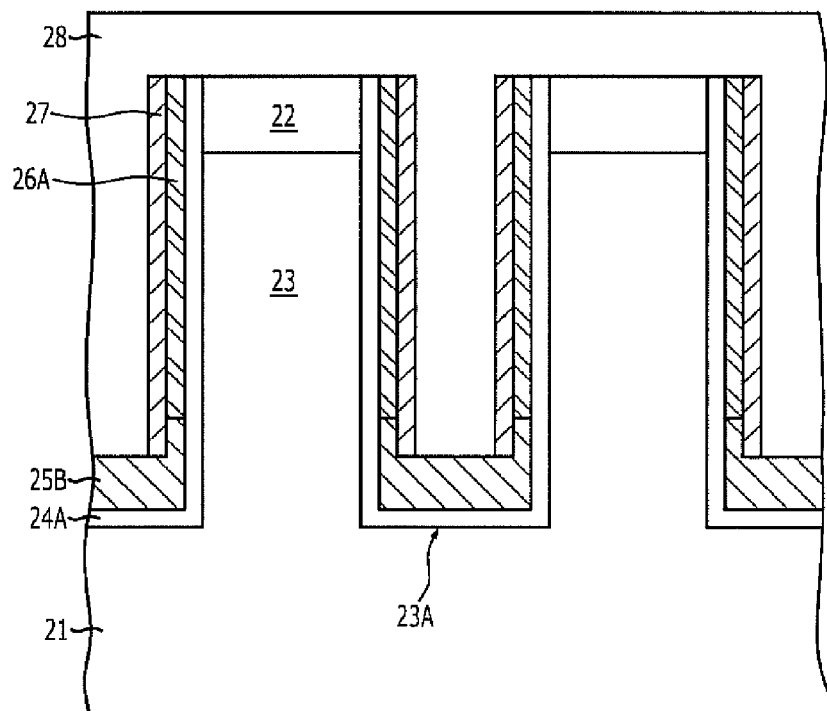


FIG. 7G

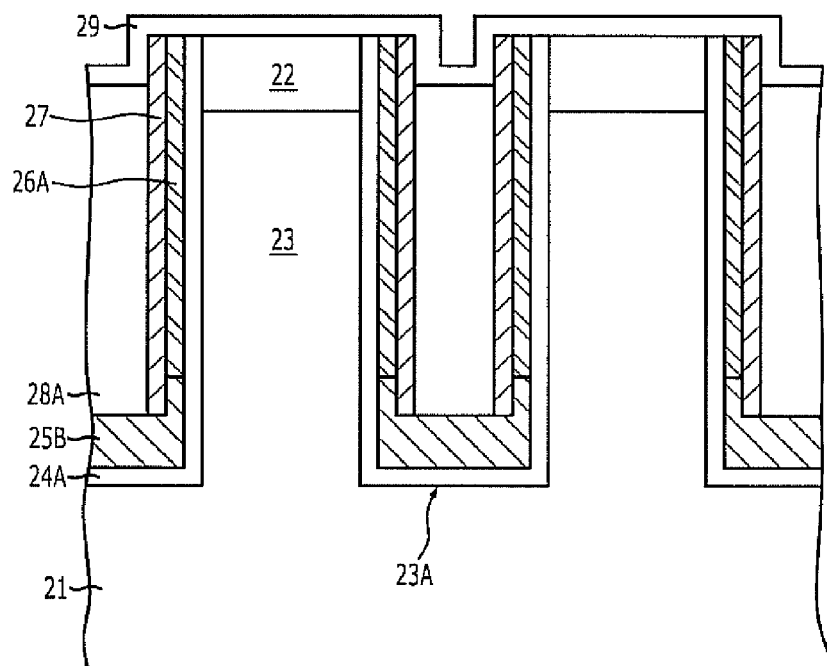


FIG. 7H

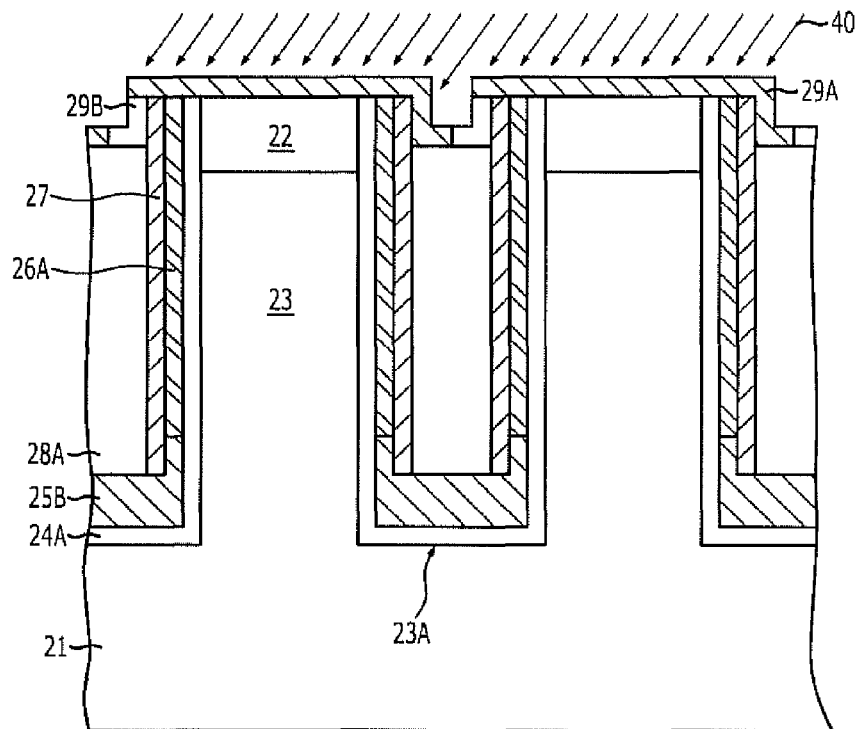


FIG. 7I

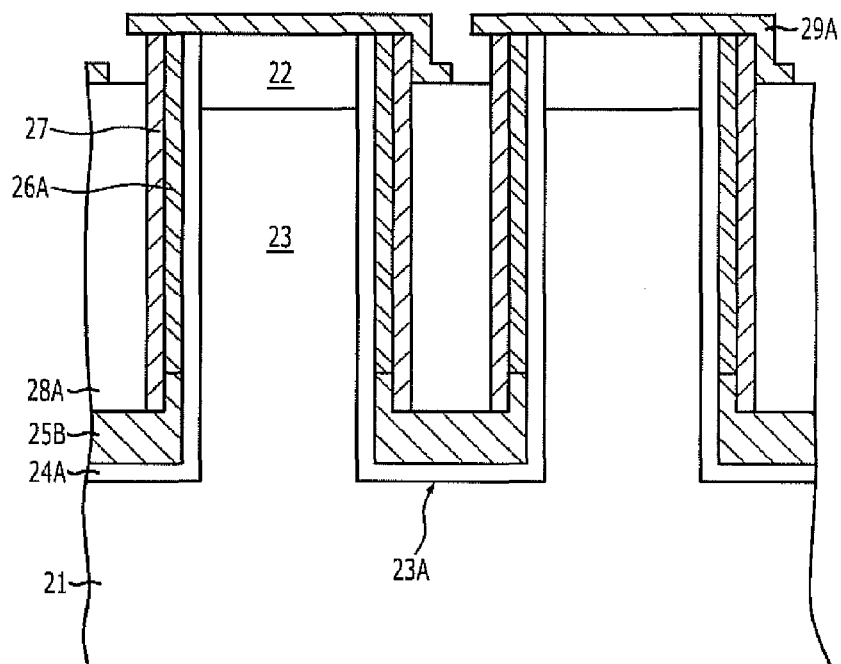


FIG. 7J

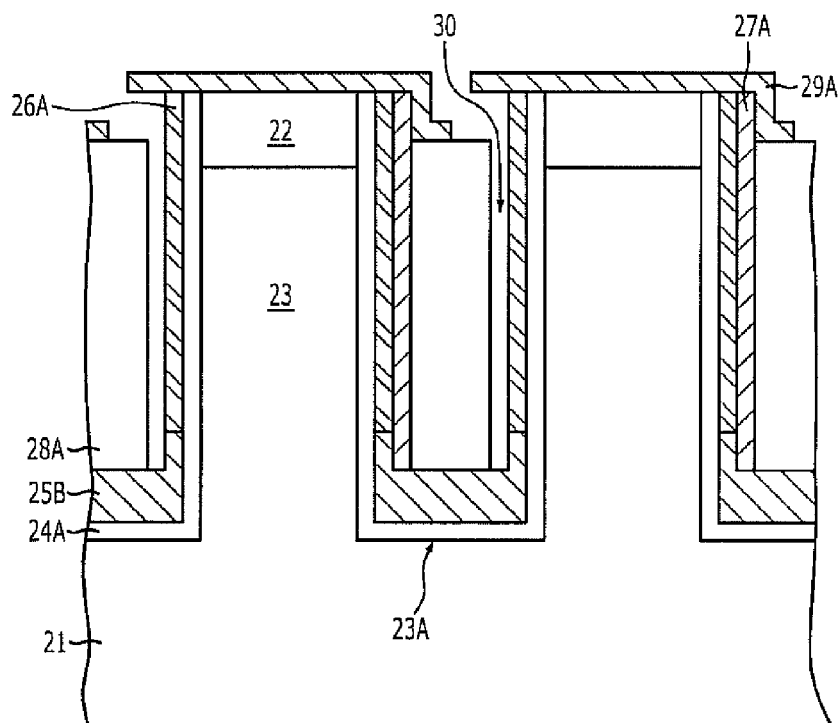


FIG. 7K

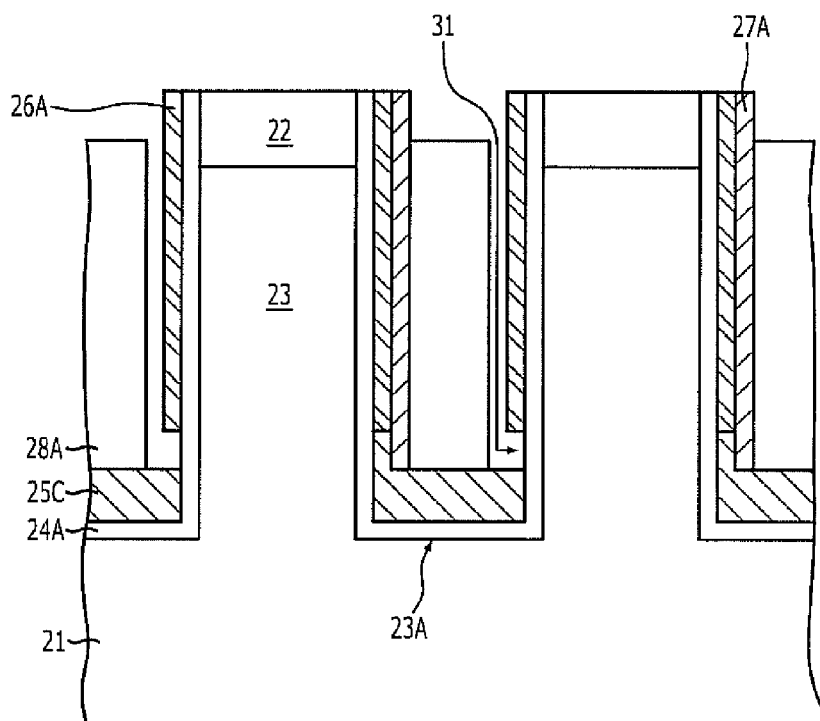
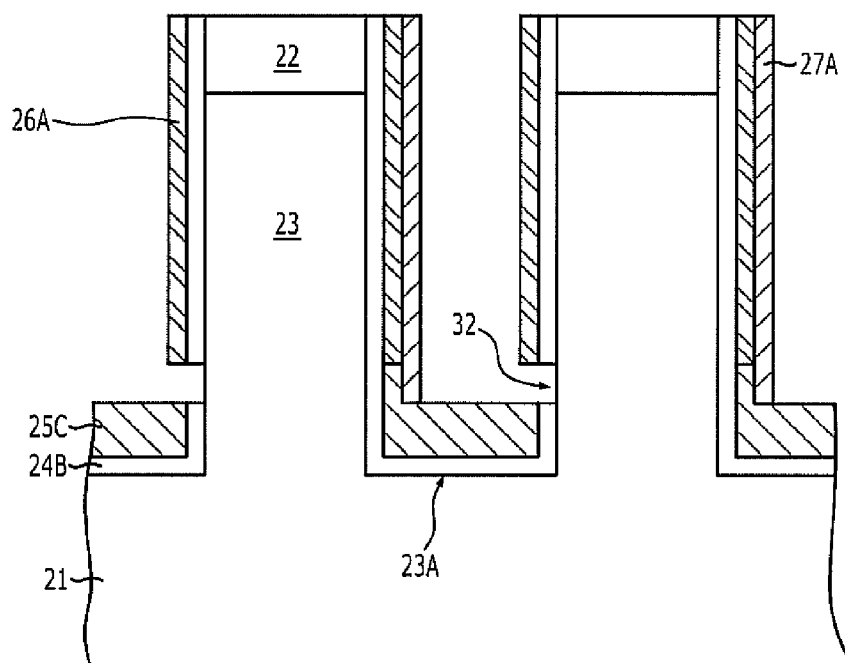


FIG. 7L



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PLASMA DOPING METHOD AND METHOD FOR FABRICATING SEMICONDUCTOR DEVICE USING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a division of U.S. patent application Ser. No. 12/774,311 filed on May 5, 2010, which claims priority of Korean Patent Application No. 10-2010-0008826, filed on Jan. 29, 2010. The disclosure of each of the foregoing application is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

Exemplary embodiments of the present invention relate to a method for fabricating a semiconductor device, and more particularly, to a plasma doping method and a method for fabricating a semiconductor device using the same.

When a specific region is doped during a fabrication process of a semiconductor device, an ion beam implantation method is usually used. The ion beam implantation method is also referred to as a "beam line implantation method."

As semiconductor devices become highly integrated, complicated three-dimensional (3D) structures are being developed, but however, doping of 3D structures through the ion beam implantation method is reaching its limits.

Such a concern in doping of 3D structures is described in detail below in reference to FIG. 1. To briefly explain the background, when a particular region of a conductive structure is to be selectively doped through the ion beam implantation method, the doping is performed at a predetermined angle. This is called "tilt ion implantation."

More specifically, FIG. 1 illustrates a tilt ion implantation doping method for a semiconductor device.

Referring to FIG. 1, a substrate **11** including a plurality of conductive structures **12** is formed. The plurality of conductive structures **12** are formed over the substrate **11** with a predetermined space between them.

To dope a specific region of a conductive structure **12**, the doping is performed through a tilt ion implantation method (see reference numeral '**13**') because the gap between the conductive structures **12** is narrow and the conductive structures **12** are formed to have a predetermined height.

The tilt ion implantation **13** is performed at a certain tilt angle. However, a concern may arise in that a target region is not doped due to a shadow cast by, for example, the area **13A** of a neighboring conductive structure **12** during the tilt ion implantation **13**.

Also, although the tilt ion implantation **13** is performed, it is difficult to dope a doping target region with a desired level of doping concentration and a desired doping depth because the conductive structures **12** may be relatively tall and the gap between the conductive structures **12** may be relatively narrow.

Another way for doping a specific region of a 3D conductive structure is a method using a doped material such as doped polysilicon. When a doped material is used, a target region is doped by thermally diffusing the dopant of the doped material through an annealing process.

However, when a region is doped through thermal diffusion, it is difficult to control the doping depth and the doping dose. Further, when the doped material is removed for a subsequent process, a dopant loss occurs. Still further, it is hard to remove the doped material. Moreover, since the ther-

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mal diffusion method does not adequately control the doping depth when a shallow doping depth is required, floating body effect may occur.

SUMMARY OF THE INVENTION

An embodiment of the present invention is directed to a doping method that forms a doped region at a desired location of a three-dimensional (3D) conductive structure and controls the doping depth and doping dose of the doped region relatively easily, and a method for fabricating a semiconductor device using the same.

Another embodiment of the present invention is directed to a doping method that provides a shallow doping depth and prevents a floating body effect, and a method for fabricating a semiconductor device using the same.

In accordance with an embodiment of the present invention, a method for doping a semiconductor device includes: forming a conductive structure having a sidewall; exposing a portion of the sidewall of the conductive structure; and forming a doped region in the exposed portion of the sidewall by performing a plasma doping process.

The method may further include: forming a protective layer on a surface of the doped region; and performing an annealing process to activate the doped region. The method may further include: forming a protective layer on the surface of the doped region by performing an annealing process for activating the doped region.

In accordance with another embodiment of the present invention, a method for fabricating a semiconductor device includes: forming an active region having a sidewall by etching a substrate; exposing a portion of the sidewall of the active region; forming a junction in the exposed portion of the sidewall by performing a plasma doping process; and forming a protective layer on a surface of the junction.

The method may further include: removing the protective layer; forming a side contact coupled to the junction; and forming a buried bit line electrically coupled to the junction through the side contact. The forming of the protective layer may be performed while an annealing process for activating the junction is performed simultaneously.

In accordance with yet another embodiment of the present invention, a method for fabricating a semiconductor device includes: forming a conductive structure having a sidewall by etching a substrate with a hard mask pattern used as an etch barrier; forming a liner layer covering the conductive structure; forming a first anti-doping layer filling a portion of a gap between the conductive structure and a second anti-doping layer covering a first sidewall of each of the conductive structure over the liner layer; forming a contact region exposing a portion of a second sidewall of the conductive structure by removing the liner layer and a portion of the first anti-doping layer formed over the second sidewall; forming a junction in the contact region by performing a plasma doping process; removing the second anti-doping layer; forming a protective layer on a surface of the junction; and removing the first anti-doping layer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a tilt-ion-implantation doping method for a semiconductor device.

FIGS. 2A and 2B are cross-sectional views illustrating a doping method for a semiconductor device in accordance with a first embodiment of the present invention.

FIGS. 3A to 3E are cross-sectional views illustrating a doping method for a semiconductor device in accordance with a second embodiment of the present invention.

FIGS. 4A to 4C are cross-sectional views illustrating a semiconductor device fabrication method using the doping method according to the second embodiment of the present invention.

FIGS. 5A to 5D are cross-sectional views illustrating a doping method for a semiconductor device in accordance with a third embodiment of the present invention.

FIGS. 6A to 6C are cross-sectional views illustrating a semiconductor device fabrication method using the doping method according to the third embodiment of the present invention.

FIGS. 7A to 7L are cross-sectional views illustrating a method for forming an opening in accordance with the first to third embodiments of the present invention.

DESCRIPTION OF SPECIFIC EMBODIMENTS

Exemplary embodiments of the present invention will be described below in more detail with reference to the accompanying drawings. The present invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present invention to those skilled in the art. Throughout the disclosure, like reference numerals refer to like parts throughout the various figures and embodiments of the present invention.

The drawings are not necessarily to scale and in some instances, proportions may have been exaggerated in order to clearly illustrate features of the embodiments. When a first layer is referred to as being “on” a second layer or “on” a substrate, it not only refers to a case where the first layer is formed directly on the second layer or the substrate but also a case where a third layer exists between the first layer and the second layer or the substrate.

FIGS. 2A and 2B are cross-sectional views illustrating a doping method for a semiconductor device in accordance with a first embodiment of the present invention.

Referring to FIG. 2A, a plurality of conductive structures **203** are formed over a substrate **201**. The substrate **201** includes a silicon substrate. The conductive structures **203** are formed by etching the substrate **201**. Since the substrate **201** includes a silicon substrate, the conductive structures **203** include silicon as well. The conductive structures **203** extend on the surface of the substrate **201** in a direction perpendicular to the illustration page for FIG. 2A. The conductive structures **203** include line-type pillars (that is, pillars each forming a line). The conductive structures **203** include an active region. The active region is an area where a channel region, a source region, and a drain region of a transistor are formed. The source region and the drain region are also referred to as a “junction.” The conductive structures **203** have sidewalls, which include at least a first sidewall and a second sidewall. Since the conductive structures **203** include an active region in the form of a pillar-type active region having a line shape. The line-shaped pillar-type active region is called “line-type active pillar.”

A hard mask layer **202** is formed over the upper portions of the conductive structures **203**. The hard mask layer **202** functions as an etch barrier in forming the conductive structures **203**. The hard mask layer **202** may be formed of a dielectric material, such as an oxide and a nitride. According to an

example, a nitride layer is used as the hard mask layer **202**. The hard mask layer **202** may also include a silicon nitride layer.

An insulation layer is formed on both sidewalls of the conductive structures **203**, the surface of the substrate **201** between the conductive structures **203**, and the sidewalls of the hard mask layer **202**. The insulation layer includes a first liner layer **204** and a second liner layer **205**. The first liner layer **204** includes an oxide layer such as a silicon oxide layer. The second liner layer **205** includes a nitride layer such as a silicon nitride layer.

An opening **208** is formed by removing a portion of the insulation layer. The opening **208** has a one-side-opening (OSO) structure which selectively exposes a portion of the sidewalls of a conductive structure **203**. The opening **208** may be a line-type opening.

A first anti-doping layer **206** and a second anti-doping layer **207** are formed on the surface of the insulation layer. The first anti-doping layer **206** fills a portion of the gap between the conductive structures **203**. The second anti-doping layer **207** is formed on the insulation layer over an unopened sidewall of the conductive structure **203** that is opposite from the sidewall where the opening **208** is formed. The first anti-doping layer **206** protects the substrate **201** between the conductive structures **203** from being doped during a subsequent plasma doping process. The second anti-doping layer **207** protects the unopened sidewall of the conductive structure **203** from being doped during a subsequent plasma doping process. The first anti-doping layer **206** and the second anti-doping layer **207** operate as an insulation layer. The first anti-doping layer **206** includes undoped polysilicon. The second anti-doping layer **207** includes a material having a selectivity with respect to the first anti-doping layer **206**, the first liner layer **204**, and the second liner layer **205**. The second anti-doping layer **207** may include a metal nitride layer, such as titanium nitride (TiN) layer. The second anti-doping layer **207** may be formed of a spacer.

The insulation layer providing the opening **208** and the hard mask layer **202** may function as an anti-doping layer as well. Plasma doping is performed onto a portion of the sidewalls of the conductive structure **203** exposed through the opening **208** and not to other portions.

The first liner layer **204**, the second liner layer **205**, the first anti-doping layer **206**, and the second anti-doping layer **207** function as anti-doping layers. The anti-doping layers provide the opening **208** exposing a portion of the sidewalls of the conductive structure **203**. A method for forming the opening **208** will be described later with reference to FIGS. 7A to 7I.

Referring to FIG. 2B, a plasma doping process **209** is performed. Herein, a portion of the sidewalls of the conductive structure **203** exposed through the opening **208** is doped. As a result, a doped region **210** is formed. The doped region **210** includes a junction, which becomes a source region and a drain region of a transistor. The doped region **210** is formed on a portion of the sidewalls of a conductive structure **203** to constitute a one-side-junction (OSJ). Since the doped region **210** is formed through a plasma doping process **209**, it forms a shallow sidewall junction.

During the plasma doping process **209**, the upper portions of the conductive structures **203** are protected from being doped by the hard mask layer **202**. The other sidewalls of the conductive structures **203** except for the portion of the sidewalls exposed through the opening **208** are protected by the first liner layer **204**, the second liner layer **205**, the first anti-doping layer **206** and the second anti-doping layer **207** from being doped (see reference signs A, B, and C). As to the first

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anti-doping layer **206** and the second anti-doping layer **207**, they contribute to protecting the other sidewalls from being doped with a dopant except for the portion of the sidewalls exposed through the opening **208**.

The plasma doping process **209** is a doping method of exciting a doping source into a plasma status and implanting dopant ions in the excited plasma into a specimen. For example, when a bias voltage is applied to the specimen, the dopant ions in the plasma may simultaneously gather over the surface of the specimen. Herein, the bias voltage may be referred to as doping energy.

The plasma doping process **209** is performed using a source of doping energy, a doping dose, and a doping source.

The doping source is a material containing a dopant to be applied to the doped region **210**. The doping source includes a dopant gas. In the first embodiment of the present invention, the doping source may be a dopant gas such as arsenic (As) and phosphorus (P). For example, the doping source may include arsine (AsH₃) or phosphine (PH₃). The arsenic (As) and phosphorus (P) are well-known N-type dopants. Also, a dopant gas containing boron (B) may be used as the doping source. Boron is a well-known P-type dopant.

The doping energy signifies a bias voltage applied to the substrate **201**. The doping energy may be a voltage not higher than approximately 20 KV. To achieve a shallow depth of the doped area, the doping energy is adjusted to be as small as possible. For example, the doping energy may be lower than approximately 1 KV, while doping energy lower than approximately 20 KV is considered to be relatively low. Since ion implantation is generally performed based on projection range (Rp), high doping energy over approximately 30 KeV may be used. In performing the process, the doping energy is applied to the conductive structures **203** as well. Thus, the plasma doping process **209** may be performed in a sidewall direction (that is, a direction facing a sidewall). By the collision of ions in the excited plasma, the plasma doping process **209** performed in the sidewall direction is facilitated.

The doping dose affects the implantation amount of a dopant. The doping dose ranges from approximately 1×10^{15} to approximately 1×10^{17} atoms/cm². When the plasma doping process **209** is performed using the doping dose of the above-described range, the dopant applied to the doped region **210** forms a doping concentration of at least more than 1×10^{20} atoms/cm³.

To facilitate the plasma doping process **209**, a gas for exciting the plasma may be introduced. The gas for exciting the plasma includes argon (Ar), helium (He) and so forth.

According to the above-described embodiment of the present invention described above, use of a tilt angle in the plasma doping process **209** may be avoided. Therefore, it is possible to perform doping without a shadow effect caused by a neighboring structure. As a result, the doped region **210** may be formed at a desired location.

Since the plasma doping process **209** uses a low doping energy of lower than approximately 20 KV, most of the dopant remains on the surface. Therefore, the doping depth of the doped region **210** formed by the plasma doping process **209** may be controlled to be shallow. Since the doping depth of the doped region **210** is controlled to be shallow, the floating body effect is prevented/reduced.

FIGS. 3A to 3E are cross-sectional views illustrating a doping method for a semiconductor device in accordance with a second embodiment of the present invention.

Referring to FIG. 3A, a plurality of conductive structures **303** are formed over a substrate **301**. The substrate **301** includes a silicon substrate. The conductive structures **303** are formed by etching the substrate **201**. Since the substrate **301**

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includes a silicon substrate, the conductive structures **303** include silicon as well. The conductive structures **303** extend on the surface of the substrate **301** in a direction perpendicular to the illustration page for FIG. 3A. The conductive structures **303** include line-type pillars (that is, pillars each forming a line). The conductive structures **303** include an active region. The active region is an area where a channel region, a source region, and a drain region of a transistor are formed. The source region and the drain region are also referred to as a "junction". The conductive structures **303** have sidewalls, which include at least a first sidewall and a second sidewall. Since the conductive structures **303** include the active region in the form of a pillar-type active region having a line shape. The line-shaped pillar-type active region is called "line-type active pillar."

A hard mask layer **302** is formed over the upper portions of the conductive structures **303**. The hard mask layer **302** functions as an etch barrier in forming the conductive structures **303**. The hard mask layer **302** may be formed of a dielectric material, such as an oxide and a nitride. According to an example, a nitride layer is used as the hard mask layer **302**. The hard mask layer **302** may include a silicon nitride layer.

An insulation layer is formed on both sidewalls of the conductive structures **303**, the surface of the substrate **301** between the conductive structures **303**, and the sidewalls of the hard mask layer **302**. The insulation layer includes a first liner layer **304** and a second liner layer **305**. The first liner layer **304** includes an oxide layer such as a silicon oxide layer. The second liner layer **305** includes a nitride layer such as a silicon nitride layer.

An opening **308** is formed by removing a portion of the insulation layer. The opening **208** has a one-side-opening (OSO) structure which selectively exposes a portion of the sidewalls of a conductive structure **303**. The opening **308** may be a line-type opening.

A first anti-doping layer **306** and a second anti-doping layer **307** are formed on the surface of the insulation layer. The first anti-doping layer **306** fills a portion of the gap between the conductive structures **303**. The second anti-doping layer **307** is formed on the insulation layer over an unopened sidewall of the conductive structure **303** that is opposite from the sidewall where the opening **308** is formed. The first anti-doping layer **306** protects the substrate **301** between the conductive structures **303** from being doped during a subsequent plasma doping process. The second anti-doping layer **307** protects the unopened sidewall of the conductive structure **303** from being doped during a subsequent plasma doping process. The first anti-doping layer **306** and the second anti-doping layer **307** operate as an insulation layer. The first anti-doping layer **306** includes undoped polysilicon. The second anti-doping layer **307** includes a material having a selectivity with respect to the first anti-doping layer **306**, the first liner layer **304**, and the second liner layer **305**. The second anti-doping layer **307** may include a metal nitride layer, such as titanium nitride (TiN) layer. The second anti-doping layer **307** may be formed of a spacer.

The insulation layer providing the opening **308** and the hard mask layer **302** may function as an anti-doping layer as well. Plasma doping is performed onto a portion of the sidewalls of the conductive structure **303** exposed through the opening **308** and not to other portions.

The first liner layer **304**, the second liner layer **305**, the first anti-doping layer **306**, and the second anti-doping layer **307** function as anti-doping layers. The anti-doping layers provide the opening **308** exposing a portion of the sidewalls of

the conductive structure **303**. A method for forming the opening **308** will be described later with reference to FIGS. 7A to 7I.

Referring to FIG. 3B, a plasma doping process **309** is performed. Herein, a portion of the sidewalls of the conductive structure **303** exposed through the opening **308** is doped. As a result, a doped region **310** is formed. The doped region **310** includes a junction, which becomes a source region and a drain region of a transistor. The doped region **310** is formed on a portion of the sidewalls of a conductive structure **303** to constitute a one-side-junction (OSJ). Since the doped region **310** is formed through a plasma doping process **309**, it forms a shallow sidewall junction.

During the plasma doping process **309**, the upper portions of the conductive structures **303** are protected from being doped by the hard mask layer **302**. The other sidewalls of the conductive structures **303** except for the portion of the sidewalls exposed through the opening **308** are protected by the first liner layer **304**, the second liner layer **305**, the first anti-doping layer **306** and the second anti-doping layer **307** from being doped (see reference signs A, B, and C). As to the first anti-doping layer **306** and the second anti-doping layer **307**, they contribute to protecting the other sidewalls from being doped with a dopant except for the portion of the sidewalls exposed through the opening **208**.

The plasma doping process **309** is a doping method of exciting a doping source into a plasma status and implanting dopant ions in the excited plasma into a specimen. For example, when a bias voltage is applied to the specimen, the dopant ions in the plasma may simultaneously gather over the surface of the specimen. Herein, the bias voltage may be referred to as doping energy.

The plasma doping process **309** is performed using a source of doping energy, a doping dose, and a doping source.

The doping source is a material containing a dopant to be applied to the doped region **310**. The doping source includes a dopant gas. In the second embodiment of the present invention, the doping source may be a dopant gas containing arsenic (As) and phosphorus (P). For example, the doping source includes arsine (AsH_3) or phosphine (PH_3). The arsenic (As) and phosphorus (P) are well-known N-type dopants. Also, a dopant gas containing boron (B) may be used as the doping source. Boron is well-known P-type dopant.

The doping energy signifies a bias voltage applied to the substrate **301**. The doping energy may be a voltage not higher than at least approximately 20 KV. To achieve a shallow depth of the doped area, the doping energy is adjusted to be as small as possible. For example, the doping energy may be lower than approximately 1 KV, while doping energy lower than approximately 20 KV is considered to be relatively low. Since ion implantation is generally performed based on projection range (R_p), high doping energy over approximately 30 KeV may be used. In performing the process, the doping energy is applied to the conductive structures **303** as well. Thus, the plasma doping process **309** may be performed in a sidewall direction (that is, a direction facing a sidewall). By the collision of ions in the excited plasma, the plasma doping process **309** performed in the sidewall direction is facilitated.

The doping dose affects the implantation amount of a dopant. The doping dose ranges from approximately 1×10^{15} to approximately 1×10^{17} atoms/cm². When the plasma doping process **309** is performed using the doping dose of the above-described range, the dopant applied to the doped region **310** forms a doping concentration of at least more than 1×10^{20} atoms/cm³.

To facilitate the plasma doping process **309**, a gas for exciting the plasma may be introduced. The gas for exciting the plasma includes argon (Ar), helium (He) and so forth.

Referring to FIG. 3C, subsequent to the above-described steps for FIGS. 3A-3B, the second anti-doping layer **307** is removed. Subsequently, a protective layer **311** is formed on the surface of the doped region **310**. The protective layer **311** protects the dopant of the doped region **310** from being lost during a subsequent process, such as a process of removing the first anti-doping layer **306**.

In the second embodiment, the protective layer **311** is formed through a furnace oxidation or plasma oxidation, where the protective layer **311** is formed with a thickness of 50 Å.

Referring to FIG. 3D, an annealing process **312** is performed to activate the dopant doping the doped region **310**. The annealing process **312** may be a rapid thermal annealing (RTA).

Referring to FIG. 3E, the first anti-doping layer **306** is removed. The first anti-doping layer **306** is removed through an etch process or a cleaning process. For example, when the first anti-doping layer **306** includes undoped polysilicon, a wet chemical or an etching gas capable of selectively removing polysilicon is used.

Since the first anti-doping layer **306** is removed after the formation of the protective layer **311**, the loss of the dopant doping the doped region **310** is minimized/reduced.

Although not illustrated in the drawing, a structure linked to the side of the doped region **310** is formed subsequently for the second embodiment. The structure may, for example, be a bit line, a capacitor or a metal line.

According to the second embodiment of the present invention described above, use of a tilt angle in the plasma doping process **309** may be avoided. Therefore, doping may be performed without a shadow effect caused by a neighboring structure. As a result, the doped region **310** may be formed at a desired location.

Since the plasma doping process **309** uses a low doping energy of lower than approximately 20 KV, most of the dopant remains on the surface. Therefore, the doping depth of the doped region **310** formed by the plasma doping process **309** may be controlled to be shallow. Since the doping depth of the doped region **310** is controlled to be shallow, the floating body effect is prevented/reduced.

Also, since the loss of the dopant doping the doped region **310** is suppressed in the second embodiment, the doping concentration is maintained to be higher than 10^{20} atoms/cm³.

FIGS. 4A to 4C are cross-sectional views illustrating a semiconductor device fabrication method using the doping method according to the second embodiment of the present invention. The drawings show cross-sectional views after the protective layer **311** and the doped region **310** are formed as shown in FIGS. 3A to 3E and the subsequent removal of the protective layer **311** as described below. The doped region **310** may function as a junction which becomes a source region or a drain region. Hereafter, a method for forming a buried bit line coupled to the doped region **310** will be described.

Referring to FIG. 4A, the protective layer **311** is removed. Accordingly, a contact region **313** exposing a side of the doped region **310** is formed. The contact region **313** has the same shape as the opening **308**.

Referring to FIG. 4B, a side contact **314** coupled to the conductive structure **303** is formed, where the side contact **314** may be a metal silicide. Examples of the metal silicide include titanium silicide (TiSi_2), cobalt silicide (CoSi_2), and

nickel silicide (NiSi). For example, titanium silicide (TiSi_2) is formed by sequentially depositing a titanium (Ti) layer and a titanium nitride (TiN) layer and performing a thermal treatment. Subsequently, titanium not reacted with the titanium nitride is removed. The titanium reacted with the titanium nitride may remain, where it forms barrier metal. Alternatively, cobalt silicide (CoSi_2), which is more stable at a high temperature, may be selected in order to prevent deterioration during a subsequent high-temperature thermal treatment. The side contact **314** may be referred to as “a buried strap filling the contact region **313**.”

According to the above description, the side contact **314** has a one-side-contact (OSC) structure formed on one side of the conductive structure **303**. When the side contact **314** is formed of a metal silicide, the concentration of the dopant doping the doped region **310** is maintained over 10^{20} atoms/ cm^3 . Therefore, silicide may be formed relatively easily.

Referring to FIG. **4C**, a bit line conductive layer is deposited over the structure with the side contact **314** formed therein. The bit line conductive layer is deposited so as to fill the gap between the conductive structures **303**. The bit line conductive layer includes a metal layer, such as titanium nitride (TiN) layer and a tungsten (W) layer. For example, the bit line conductive layer may be formed by stacking a titanium nitride layer and a tungsten (TiN/W) layer.

Subsequently, the bit line conductive layer is removed up to a certain height where a contact with the side contact **314** is maintained. Accordingly, a buried bit line **315** contacting the side contact **314** is formed. Here, the buried bit line **315** is arranged in parallel with the conductive structures **303**, and the doped region **310** is electrically coupled to the buried bit line **315** through the side contact **314**. The side contact **314** forms an ohmic contact between the doped region **310** and the buried bit line **315**.

FIGS. **5A** to **5D** are cross-sectional views illustrating a doping method for a semiconductor device in accordance with a third embodiment of the present invention.

Referring to FIG. **5A**, a plurality of conductive structures **403** are formed over a substrate **401**. The substrate **401** includes a silicon substrate. The conductive structures **403** are formed by etching the substrate **401**. Since the substrate **401** includes a silicon substrate, the conductive structures **403** include silicon as well. The conductive structures **403** extend the surface of the substrate **401** in a direction perpendicular to the illustration page for FIG. **5A**. The conductive structures **403** include line-type pillars (that is, pillars each forming a line). The conductive structures **403** include an active region. The active region is an area where a channel region, a source region, and a drain region of a transistor are formed. The source region and the drain region are also referred to as a “junction”. The conductive structures **403** have sidewalls, which include at least a first sidewall and a second sidewall. Since the conductive structures **403** include an active region in the form of a pillar-type active region having a line shape. The line-shaped pillar-type active region is called “line-type active pillar.”

A hard mask layer **402** is formed over the upper portions of the conductive structures **403**. The hard mask layer **402** functions as an etch barrier in forming the conductive structures **403**. The hard mask layer **402** may be formed of a dielectric material, such as an oxide and a nitride. According to an example, a nitride layer is used as the hard mask layer **402**. The hard mask layer **402** may include a silicon nitride layer.

An insulation layer is formed on both sidewalls of the conductive structures **403**, the surface of the substrate **401** between the conductive structures **403**, and the sidewalls of the hard mask layer **402**. The insulation layer includes a first

liner layer **404** and a second liner layer **405**. The first liner layer **404** includes an oxide layer such as a silicon oxide layer. The second liner layer **405** includes a nitride layer such as a silicon nitride layer.

An opening **408** is formed by removing a portion of the insulation layer. The opening **408** has a one-side-opening (OSO) structure which selectively exposes a portion of the sidewalls of a conductive structure **403**. The opening **408** may include a line-type opening.

A first anti-doping layer **406** and a second anti-doping layer **407** are formed on the surface of the insulation layer. The first anti-doping layer **406** fills a portion of the gap between the conductive structures **403**. The second anti-doping layer **407** is formed on the insulation layer an unopened sidewall of the conductive structure **403** that is opposite from the sidewall where the opening **408** is formed. The first anti-doping layer **406** protects the substrate **401** between the conductive structures **403** from being doped during a subsequent plasma doping process. The second anti-doping layer **407** protects the unopened sidewall of the conductive structure **403** from being doped during a subsequent plasma doping process. The first anti-doping layer **406** and the second anti-doping layer **407** operate as an insulation layer. The first anti-doping layer **406** includes undoped polysilicon. The second anti-doping layer **407** includes a material having a selectivity with respect to the first anti-doping layer **406**, the first liner layer **404**, and the second liner layer **405**. The second anti-doping layer **407** may include a metal nitride layer, such as titanium nitride (TiN) layer. The second anti-doping layer **407** may be formed of a spacer.

The insulation layer providing the opening **408** and the hard mask layer **402** may function as anti-doping layer as well. Plasma doping is performed onto a portion of the sidewalls of the conductive structure **303** exposed through the opening **408** and not to other portions.

The first liner layer **404**, the second liner layer **405**, the first anti-doping layer **406**, and the second anti-doping layer **407** function as anti-doping layers. The anti-doping layers provide the opening **408** exposing a portion of the sidewalls of the conductive structure **403**. A method for forming the opening **408** will be described later with reference to FIGS. **7A** to **7I**.

Referring to FIG. **5B**, a plasma doping process **409** is performed. Herein, a portion of the sidewalls of the conductive structure **403** exposed through the opening **408** is doped. As a result, a doped region **410** is formed. The doped region **410** includes a junction, which becomes a source region and a drain region of a transistor. The doped region **410** is formed on a portion of the sidewalls of a conductive structure **403** to constitute a one-side-junction (OSJ). Since the doped region **410** is formed through a plasma doping process **409**, it forms a shallow sidewall junction.

During the plasma doping process **409**, the upper portions of the conductive structures **403** are protected from being doped by the hard mask layer **402**. The other sidewalls of the conductive structures **403** except for the portion of the sidewalls exposed through the opening **408** are protected by the first liner layer **404**, the second liner layer **405**, the first anti-doping layer **406** and the second anti-doping layer **407** from being doped (see reference signs A, B, and C). As to the first anti-doping layer **406** and the second anti-doping layer **407**, they contribute to protecting the other sidewalls from being doped with a dopant except for the portion of the sidewalls exposed through the opening **408**.

The plasma doping process **409** is a doping method of exciting a doping source into a plasma status and implanting dopant ions in the excited plasma into a specimen. For

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example, when a bias voltage is applied to the specimen, the dopant ions in the plasma may simultaneously gather over the surface of the specimen. Herein, the bias voltage may be referred to as doping energy.

The plasma doping process **409** is performed using a source of doping energy, a doping dose, and a doping source.

The doping source is a material containing a dopant to be applied to the doped region **410**. The doping source includes a dopant gas. In the third embodiment of the present invention, the doping source may be a dopant gas containing arsenic (As) and phosphorus (P). For example, the doping source may include arsine (AsH₃) or phosphine (PH₃). The arsenic (As) and phosphorus (P) are well-known N-type dopants. Also, a dopant gas containing boron (B) may be used as the doping source. Boron is well-known P-type dopant.

The doping energy signifies a bias voltage applied to the substrate **401**. The doping energy may be a voltage not higher than at least approximately 20 KV. To achieve a shallow depth of the doped area, the doping energy is adjusted to be as small as possible. For example, the doping energy may be lower than approximately 1 KV, while doping energy lower than approximately 20 KV is considered to be relatively low. Since ion implantation is generally performed based on projection range (Rp), high doping energy over approximately 30 KeV may be used. In performing the process, the doping energy is applied to the conductive structures **403** as well. Thus, the plasma doping process **409** may be performed in a sidewall direction (that is, a direction facing a sidewall). By the collision of ions in the excited plasma, the plasma doping process **409** performed in the sidewall direction is facilitated.

The doping dose affects the implantation amount of a dopant. The doping dose ranges from approximately 1×10^{15} to approximately 1×10^{17} atoms/cm². When the plasma doping process **309** is performed using the doping dose of the above-described range, the dopant applied to the doped region **410** forms a doping concentration of at least more than 1×10^{20} atoms/cm³.

To facilitate the plasma doping process **409**, a gas for exciting the plasma may be introduced. The gas for exciting the plasma includes argon (Ar), helium (He) and so forth.

Referring to FIG. 5C, subsequent to the above-described steps for FIGS. 5A-5B, the second anti-doping layer **407** is removed. Subsequently, a protective layer **411** is formed on the surface of the doped region **410**. The protective layer **411** is formed while performing an annealing process **412** for activating the dopant doping the doped region **410**. The protective layer **411** protects the dopant of the doped region **410** from being lost during a subsequent process, such as a process of removing the first anti-doping layer **406**.

In the third embodiment, a rapid thermal treatment (RTA) is used to perform the annealing process **412** while forming the protective layer **411**. The protective layer **411** is formed by supplying an oxygen-containing gas or a nitrogen-containing gas while the rapid thermal treatment is performed simultaneously. The oxygen-containing gas may be oxygen gas. The nitrogen-containing gas may be nitrogen trifluoride (NF₃) gas. When the oxygen-containing gas flows in, the protective layer **411** turns into an oxide layer. When the nitrogen-containing gas flows in, the protective layer **411** turns into a nitride layer.

Referring to FIG. 5D, the first anti-doping layer **406** is removed. The first anti-doping layer **406** is removed through an etch process or a cleaning process. For example, when the first anti-doping layer **406** includes undoped polysilicon, a wet chemical or an etching gas capable of selectively removing polysilicon is used.

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Since the first anti-doping layer **406** is removed after the formation of the protective layer **411**, the loss of the dopant doping the doped region **410** is minimized/reduced.

Although not illustrated in the drawing, a structure linked to the side of the doped region **410** is formed subsequently for the second embodiment. The structure may, for example, be a bit line, a capacitor or metal line.

According to the third embodiment of the present invention described above, use of a tilt angle in the plasma doping process **409** may be avoided. Therefore, it is possible to perform doping without a shadow effect caused by a neighboring structure. As a result, the doped region **410** may be formed at a desired location.

Since the plasma doping process **409** uses a low doping energy of lower than approximately 20 KV, most of the dopant remains on the surface. Therefore, the doping depth of the doped region **410** formed by the plasma doping process **409** may be controlled to be shallow. Since the doping depth of the doped region **410** is controlled to be shallow, the floating body effect is prevented/reduced.

Also, since the loss of the dopant doping the doped region **310** is suppressed in the second embodiment, the doping concentration is maintained to be higher than 10^{20} atoms/cm³.

FIGS. 6A to 6C are cross-sectional views illustrating a semiconductor device fabrication method using the doping method according to the third embodiment of the present invention. The drawings show cross-sectional views after the protective layer **411** and the doped region **410** are formed as shown in FIGS. 5A to 5D. The doped region **410** may function as a junction which becomes a source region or a drain region.

Hereafter, a method for forming a buried bit line coupled to the doped region **410** will be described.

Referring to FIG. 6A, the protective layer **411** is removed. Accordingly, a contact region **413** exposing a side of the doped region **410** is formed. The contact region **413** has the same shape as the opening **408**.

Referring to FIG. 6B, a side contact **414** coupled to the conductive structure **403** is formed, where the side contact **414** may be a metal silicide. Examples of the metal silicide include titanium silicide (TiSi₂), cobalt silicide (CoSi₂), and nickel silicide (NiSi). For example, titanium silicide (TiSi₂) is formed by sequentially depositing a titanium (Ti) layer and a titanium nitride (TiN) layer and performing a thermal treatment. Subsequently, titanium not reacted with the titanium nitride is removed. The titanium reacted with the titanium nitride may remain, where it forms barrier metal. Alternatively, cobalt silicide (CoSi₂), which is more stable at a high temperature, may be selected in order to prevent deterioration during a subsequent high-temperature thermal treatment. The side contact **414** fills the contact region **413**. The side contact **414** may be referred to as "a buried strap filling the contact region **413**."

According to the above description, the side contact **414** has a one-side-contact (OSC) structure formed on one side of the conductive structure **403**. When the side contact **414** is formed of a metal silicide, the concentration of the dopant doping the doped region **410** is maintained over 10^{20} atoms/cm³. Therefore, silicide may be formed relatively easily.

Referring to FIG. 6C, a bit line conductive layer is deposited over the structure with the side contact **414** formed therein. The bit line conductive layer is deposited so as to fill the gap between the conductive structures **403**. The bit line conductive layer includes a metal layer, such as titanium nitride (TiN) layer and a tungsten (W) layer. For example, the bit line conductive layer may be formed by stacking a titanium nitride layer and a tungsten (TiN/W) layer.

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Subsequently, the bit line conductive layer is removed up to a certain height where a contact with the side contact **414** is maintained. Accordingly, a buried bit line **415** contacting the side contact **414** is formed. Here, the buried bit line **415** is arranged in parallel with the conductive structures **403**, and the doped region **410** is electrically coupled to the buried bit line **415** through the side contact **414**. The side contact **414** forms an ohmic contact between the doped region **410** and the buried bit line **415**.

FIGS. 7A to 7I are cross-sectional views illustrating a method for forming an opening on a sidewall of a conductive structure in accordance with the first to third embodiments of the present invention.

Referring to FIG. 7A, a hard mask layer **22** is formed over a substrate **21**. The hard mask layer **22** includes a nitride layer. Also, the hard mask layer **22** may have a multi-layer structure including an oxide layer and a nitride layer. For example, the hard mask layer **22** may include a hard mask nitride layer and a hard mask oxide layer sequentially stacked therein. Also, the hard mask layer **22** may be a hard mask nitride layer, a hard mask oxide layer, a hard mask silicon oxynitride (SiON) and a hard mask carbon layer sequentially stacked therein. When the hard mask layer **22** includes a hard mask nitride layer, a pad oxide layer may be further formed between the substrate **21** and the hard mask layer **22**. The hard mask layer **22** is formed using a photoresist pattern, which is not shown in the drawing.

Referring to FIG. 7B, a trench etch process is performed using the hard mask layer **22** as an etch barrier. For example, conductive structures **23** are formed by etching the substrate **21** to a predetermined depth by using the hard mask layer **22** as an etch barrier. The conductive structures **23** are isolated from each other by trenches **23A** formed therebetween. Each conductive structure **23** includes an active region where a transistor is formed. The conductive structure **23** includes two sidewalls. The trench etch process includes an anisotropic etch process. When the substrate **21** is a silicon substrate, the anisotropic etch process may include a plasma dry etch process using chlorine (Cl₂) gas, hydrogen bromide (HBr) gas, or a mixed gas thereof. A plurality of conductive structures **23** are formed over a substrate **21A** by the trenches **23A**. The conductive structures **23** may be line-type pillars, e.g., line-type active pillars. Herein, the active pillars may also be referred to as "pillar-type active regions."

A first liner layer **24** is formed as an insulation layer. The first liner layer **24** includes an oxide layer, e.g., silicon oxide layer.

A first gap-fill layer **25** for gap-filling the trenches **23A** between the conductive structures **23** is formed over the first liner layer **24**. The first gap-fill layer **25** may be undoped polysilicon or amorphous silicon.

Referring to FIG. 7C, the first gap-fill layer **25** is planarized until the surface of the hard mask layer **22** is shown. The planarization of the first gap-fill layer **25** may use a chemical mechanical polishing (CMP) process. Subsequently, an etch-back process is performed. By performing the etch-back process, a first anti-doping layer **25A** providing a first recess R1 is formed. During the chemical mechanical polishing (CMP) process, the first liner layer **24** over the hard mask layer **22** may be polished. Accordingly, a first liner pattern **24A** covering both sidewalls of the hard mask layer **22** and both sidewalls of the trenches **23A** is formed. The first liner pattern **24A** covers the bottoms of the trenches **23A** as well.

Referring to FIG. 7D, a second liner layer **26** is formed as an insulation layer over the resultant structure with the first anti-doping layer **25A** formed therein. The second liner layer **26** includes a nitride layer, e.g., silicon nitride layer.

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Referring to FIG. 7E, the second liner layer **26** is etched to thereby form a second liner pattern **26A**. Subsequently, the first anti-doping layer **25A** is recessed to a predetermined depth by using the second liner pattern **26A** as an etch barrier. As a result, a second recess R2 is formed. The first anti-doping layer with the second recess R2 is denoted by a reference numeral "25B" and referred to as "a first anti-doping pattern 25B."

Referring to FIG. 7F, a metal nitride layer is conformally formed over the resultant structure with the second recess R2 formed therein. Subsequently, a spacer etch process is performed to thereby form a second anti-doping layer **27**. The second anti-doping layer **27** is formed over both sidewalls of the conductive structure **23**. The second anti-doping layer **27** may be a titanium nitride (TiN) layer.

A second gap-fill layer **28** gap-filling the second recess R2 with the second anti-doping layer **27** is formed. The second gap-fill layer **28** includes an oxide layer. The second gap-fill layer **28** may be a spin on dielectric (SOD) layer.

Referring to FIG. 7G, the second gap-fill layer **28** is planarized and then undergoes an etch-back process. Accordingly, a recessed second gap-fill pattern **28A** is formed.

An etch barrier **29** is formed over the resultant structure with the second gap-fill pattern **28A** formed therein. The etch barrier **29** may be formed of undoped polysilicon.

Referring to FIG. 7H, a tilt ion implantation process **40** is performed.

The tilt ion implantation process **40** is performed to implant the ions of the dopant at a predetermined tilt angle. The dopant is implanted into a portion of the etch barrier **29**.

The tilt ion implantation process **40** is performed at a predetermined angle. The angle ranges from approximately 5° to approximately 30°. The hard mask layer **22** blocks a part of ion beam. Therefore, a portion of the etch barrier **29** is doped, and the others remain undoped. For example, when the dopant that is ion-implanted is a P-type dopant, e.g., boron (B), boron difluoride (BF₂) is used to ion-implant the boron. As a result, a portion of the etch barrier **29** remain undoped, which is a portion formed over the left side of the hard mask layer **22**.

A portion of the etch barrier **29** formed on the upper surface of the hard mask layer **22** by the tilt ion implantation process **40** of the dopant and a portion formed over the right side of the hard mask layer **22** become a doped etch barrier **29A** doped with the dopant. The etch barrier into which the dopant is not implanted become an undoped etch barrier **29B**.

Referring to FIG. 7I, the undoped etch barrier **29B** is shown to have been removed. Herein, polysilicon used as the etch barrier has a different etch rate according to whether it is doped with the dopant or not. Particularly, the undoped polysilicon into which the dopant is not implanted has a fast wet etch rate. Therefore, the undoped polysilicon is selectively removed using a chemical having a high selectivity, which may wet-etch, for example, only undoped polysilicon. The undoped etch barrier **29B** is removed through a wet etch process or a wet cleaning process.

When the undoped etch barrier **29B** is removed as described above, only the doped etch barrier **29A** remains.

Referring to FIG. 7J, the exposed second anti-doping layers **27** are removed. Accordingly, a first gap **30** is formed. The second anti-doping layer **27** is removed through a wet etch process, and as a result, one portion of the second anti-doping layers remains. The remaining portion of the second anti-doping layers is marked with a reference numeral "27A" and referred to as a "remaining portion 27A of the second anti-doping layers."

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Referring to FIG. 7K, the doped etch barrier 29A is removed. Herein, since both of the doped etch barrier 29A and the first anti-doping pattern 25B are formed of polysilicon, a portion of the first anti-doping pattern 25B below the second liner pattern 26A is removed. Accordingly, a second gap 31 is formed. After the second gap 31 is formed, the first anti-doping layer remains as marked with a reference numeral "25C" and referred to as "a first anti-doping portion 25C." The first liner pattern 24A is exposed through the second gap 31.

Referring to FIG. 7L, the second gap-fill pattern 28A is removed. Since both of the second gap-fill pattern 28A and the first liner pattern 24A are oxide layers, a portion of the sidewalls of the conductive structure 23 is exposed. The region exposing the portion of the sidewalls of the conductive structure 23 is referred to as an "opening 32."

In exposing the portion of the sidewalls of the conductive structure 23 corresponding to the opening 32, a cleaning process is performed.

The cleaning process may be a wet cleaning process. The wet cleaning process is performed using hydrogen fluoride (HF) or a buffered oxide etchant (BOE). With the wet cleaning process, the second gap-fill pattern 28A may be selectively removed without damaging the first anti-doping portion 25C, the remaining portion 27A of the second anti-doping layers, and the second liner pattern 26A. After the wet cleaning, an unaffected portion of the first liner pattern 24A remains. The remaining portion of the first liner pattern 24A is marked with a reference numeral "24B" and referred to as a "remaining portion 24B of the first liner pattern."

As described above, the hard mask layer 22, the remaining portion 24B of the first liner pattern, the second liner pattern 26A, the first anti-doping portion 25C, and the remaining portion 27A of the second anti-doping layers are collectively called "an anti-doping layer." Collectively, the anti-doping layer provides the opening 32 which exposes a portion of the sidewalls of the conductive structure 23.

The opening 32 corresponds to the opening 208 in FIG. 2A of the first embodiment, the opening 308 in FIG. 3A of the second embodiment, and the opening 408 in FIG. 5A of the third embodiment.

According to an exemplary embodiment of the present invention, a doped region doped with a dopant may be easily formed at a desired location of a conductive structure having a 3D structure by using a plasma doping method. Also, the doping depth and doping dose of the doped region may be controlled easily.

Moreover, since a junction is formed through the plasma doping method, shallow doping depth may be achieved and thus a shallow junction may be formed without a floating body effect.

By using the plasma doping method performed according to an exemplary embodiment of the present invention, where a shallow one-side-junction (OSJ) is formed, a semiconductor device having one-side-contacts (OSC) and buried bit lines (BBL) may be formed. In particular, a $4F^2$ scheme DRAM having a $4F^2$ structure may be implemented, where F denotes a minimum feature size, while improving throughput and reducing production costs.

While the present invention has been described with respect to the specific embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the invention disclosed herein.

What is claimed is:

1. A method for fabricating a semiconductor device, comprising:

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forming an active region having a sidewall by etching a substrate;

exposing a portion of the sidewall of the active region;

forming a junction in the exposed portion of the sidewall by performing a plasma doping process; and

forming a protective layer on a surface of the junction, wherein the exposing of the portion of the sidewall of the active region comprises:

forming a first anti-doping layer filling a portion of a gap between the active region and a second anti-doping layer covering a first sidewall of the active region; and forming an opening, which exposes a portion of a second sidewall of the active region by selectively removing a portion of the first anti-doping layer.

2. The method of claim 1, wherein further comprising: performing an annealing process to activate the junction after the forming of the protective layer.

3. The method of claim 2, wherein the annealing process includes a rapid thermal annealing (RTA).

4. The method of claim 1, wherein the forming of the protective layer comprises: oxidizing the surface of the junction.

5. The method of claim 1, wherein the forming of the protective layer is performed while an annealing process for activating the junction is performed simultaneously.

6. The method of claim 5, wherein the annealing process is performed in an atmosphere of an oxygen-containing gas.

7. The method of claim 5, wherein the annealing process is performed in an atmosphere of a nitrogen-containing gas.

8. The method of claim 1, wherein the plasma doping is performed with a doping energy of lower than approximately 20 KV in a doping dose of approximately 1×10^{15} to approximately 1×10^{17} atoms/cm².

9. The method of claim 1, wherein the anti-doping layer includes an insulation material.

10. The method of claim 1, wherein the anti-doping layer includes at least one selected from the group consisting of an oxide layer, a nitride layer, an undoped polysilicon layer, and a metal nitride layer.

11. The method of claim 1, wherein the opening is formed to open a portion of the sidewall of the active region in a line shape.

12. The method of claim 1, wherein the active region includes line-type silicon pillars each having the first sidewall and the second sidewall.

13. The method of claim 1, further comprising:

removing the protective layer;

forming a side contact coupled to the junction; and

forming a buried bit line electrically coupled to the junction through the side contact.

14. A method for fabricating a semiconductor device, comprising:

forming a conductive structure having a sidewall by etching a substrate with a hard mask pattern used as an etch barrier;

forming a liner layer covering the conductive structure;

forming a first anti-doping layer filling a portion of a gap between the conductive structure and a second anti-doping layer covering a first sidewall of the conductive structure over the liner layer;

forming a contact region exposing a portion of a second sidewall of the conductive structure by removing the liner layer and a portion of the first anti-doping layer formed over the second sidewall;

forming a junction in the contact region by performing a plasma doping process;

removing the second anti-doping layer;

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forming a protective layer on a surface of the junction; and
removing the first anti-doping layer.

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